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INTERNAL RESERVES FOR ENHANCING THE EFFICIENCY OF GLASS-MELTING FURNACES

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A set of measures has been developed and implemented allowing for improvement of the operating efficiency parameters of the glass-melting furnace through the controlled modification of the glass melt redox potential.

The analysis of glass-melting furnace operation shows that along with the external factors of the glass-melting process intensification (for instance, conversion to a better-quality material, introduction of bubbling, stirring the glass melt, additional electric heating of the melt, etc.), the internal reserves of the process are not sufficiently realized. The latter, in spite of their accessibility, low cost, easy implementation, and high efficiency) did not become the subject of extensive discussion in the technical literature.

The inspection of several glass-melting furnaces established that, in most cases, their efficiency can be improved. Chemical as well as physical methods should be used for glass melting intensification [1].

The chemical methods, in our opinion, include direct alteration of the redox potential (ROP) of the glass melt (use of melting catalysts, oxidizers, reducers, etc.). The physical methods for glass melting intensification are well known and are the most suitable for practical use (improvement of the fuel feed system and the fuel combustion process, improved operation of the charge and cullet loaders, introduction of glass melt stirring, etc.). These factors indirectly affect the ROP of the glass melt. However, the specified factors are not sufficiently described in the literature in terms of the possibility for controlling the glass melt ROP in tank furnaces. Below follows an attempt at their interpretation, as applied to glass-melting furnaces for clear sheet glass.

First of all, let us consider in detail the chemical methods for improving glass melting. They are related to the direct effect of certain factors on fluid glass inside the furnace. Therefore, the analysis and prediction of the behavior of iron in the glass melt depending on the process conditions acquire special importance.

According to current concepts [1], iron exists in the glass melts in a redox equilibrium state $\text{Fe(II)} \rightleftharpoons \text{Fe(III)}$. The position of the equilibrium depends on the ROP (basicity) of the glass mass. An increase in Fe(II) concentration in the flint

glass melt decreases the thermal transparency of the glass, thus decreasing the penetration of heat into the melt depth and promoting the origination of thermal and chemical inhomogeneity of the glass. Hence, in order to reduce the effect of negative factors, in practice it is recommended to stabilize the actual concentration of Fe(II) by means of forced preservation of the constant Fe_2O_3 content in the glass [2]. However, this method is not always reliable, since even in this event a certain part of the Fe_2O_3 can pass over to FeO , which will significantly modify the normal course of glass melting [3, 4].

The equilibrium state of $\text{Fe(II)} \rightleftharpoons \text{Fe(III)}$ depends on the temperature/time conditions of the technological process, the composition of the gas medium above the melt, the batch ROP, and the chemical composition of glass [1]. These parameters have heterogeneous effects on the glass melt basicity and, accordingly, on the equilibrium of iron valence forms in the melt. As a rule, their effect was studied on simple silicate glasses made under laboratory or industrial conditions.

In the actual production process, the specified parameters have a complex effect on glass basicity, which in the end forms a specific ratio of valence forms of iron for each glass-melting furnace.

A study of the combined effect of the technological parameters on the modification of the melt basicity and, accordingly, the equilibrium state of iron in [3] uses the glass basicity indicator which reflects the fraction of bivalent iron in the glass and in this way can indirectly characterize the modification of the batch ROP

$$d_{\text{Fe(II)}} = \frac{\text{Fe(II)} \times 100}{\text{Fe(II)} + \text{Fe(III)}}.$$

This indicator is used in the present study to analyze the ROP of the glass melt and to correct the technological process of two similarly designed furnaces for sheet glass melt-

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TABLE 1

Parameter	Tank furnace No. 1			Tank furnace No. 2		
	process 1a*	process 1b**	process 1c**	process 2a*	process 2b**	process 2c**
Composition of the charge loaded into furnace, wt. %:						
batch	73.60	73.80	73.82	73.01	71.16	71.52
cullet	25.93	25.71	25.87	26.81	27.86	27.87
Batch ROP	19.20	15.30	18.90	13.81	16.25	20.19
Impurity content, wt. %:						
Fe ₂ O ₃	0.0730	0.1180	0.1610	0.1200	0.1400	0.1300
Fe _{tot} = Fe(II) + Fe(III)	0.0510	0.0829	0.1130	0.0850	0.0920	0.0890
Fe(II)	0.0171	0.0321	0.0397	0.0270	0.0340	0.0280
Fe(II) fraction, %	33.5	38.9	35.1	31.7	36.9	31.4
Maximum temperature, °C	1520	1550	1540	1510	1530	1515
Glass melt temperature, °C, in the through channel:						
on the left	—	—	—	—	1137	1127
on the right	—	—	—	—	1144	1128
Homogeneity, °C	1.1 – 1.3	1.8 – 2.0	1.8 – 2.0	1.4	1.8 – 1.9	1.8 – 1.9
Output, ton/day	140	140	140	60.4	62.8	65.0

* Cullet, traditional material.

** Cullet, local material.

ing at the Avtosteklo company. These furnaces are regenerative, with laterally directed flame, heated by natural gas. The melting area is separated from the chilling zone by a knuckle inside which a water-chilled barrier of metal pipes is installed in the glass melt.

The chemical compositions of glass, the maximum melting temperature for the gas medium, the sources of Fe₂O₃ for the melt, and the technological properties of melts are shown in Table 1.

The chemical method for glass melting intensification was implemented in tank furnace No. 1. The technological processes numbered 1a, 1b, and 1c had similar glass compositions. The concentrations of high-melting oxides (SiO₂, Al₂O₃) and fluxes (Me₂O, MeO) were within the limits prescribed by the technological regulations. The imported materials in process 1a were replaced by a local material, which caused an increase in the Fe₂O₃ content in the glass from 0.073 to 0.118%, i.e., an increase of 61.6% (here and elsewhere mass content is indicated). To decrease the amount of seeds in the glass melt, the batch ROP was decreased from 19.2 (process 1a) to 15.3 (process 1b). At the same time, the bivalent iron content in the glass was seen to grow from 0.0171 to 0.0321%, i.e., it increased by 88%. The two factors before the last one determined the decrease in the oxidizing capacity of the glass melt (the fraction of Fe(II) increased from 33.5 to 38.9%), which resulted in decreased diathermancy of the glass melt and deterioration of the melting capacity of the furnace (the glass inhomogeneity increased from 1.1 – 1.3 to 1.8 – 2.0°C), in spite of the increase from 1520 to 1550°C in the maximum temperature measured by the gas medium.

For the purpose of decreasing the thermal stress on the main roof of tank furnace No. 1, the content of the oxidizer

(sodium sulfate) in the batch was gradually increased. The batch ROP was brought up to 18.9 (process 1c), which decreased the part of Fe(II) in the glass and increased the diathermancy of the glass melt. This, in turn, made it possible to facilitate the melting conditions: the maximum gas medium temperature was decreased to 1530 – 1540°C. A similar phenomenon was recorded in [3, 4]: an increase in the Fe₂O₃ content due to the introduction of new types of materials led to a decrease in the glass melt diathermancy and deterioration of the glass-melting process.

The above facts point to the possibility of intensifying the glass melting process by increasing the glass melt redox potential to increase the melt diathermancy.

The combined use of the chemical and physical methods for glass melting intensification was tested in glass-melting furnace No. 2 (Table 1). It is interesting to observe the dynamics of the variations in the impurity oxide (Fe₂O₃ and FeO) content in glass in the course of the technological process.

The conversion to new types of raw materials determined the necessity of replacing the traditional glass composition (process 2a) by lower-melting composition which, accordingly, has a higher degree of basicity (process 2b). In connection with the increased quantity of cullet and the decreased amount of batch loaded into the furnace, the glass composition was modified: the content of the high-melting components (SiO₂, Al₂O₃) decreased and the content of the low-melting components (Me₂O, MeO) became higher. The Fe₂O₃ content in the glass grew from 0.12 to 0.14%. In spite of the increase in the batch ROP from 13.81 (process 2a) to 16.25 (process 2b), the fraction of Fe(II) in the glass grew from 31.7 to 36.9%, due to the increased content of reducing impurities in the new material. This determined the increase

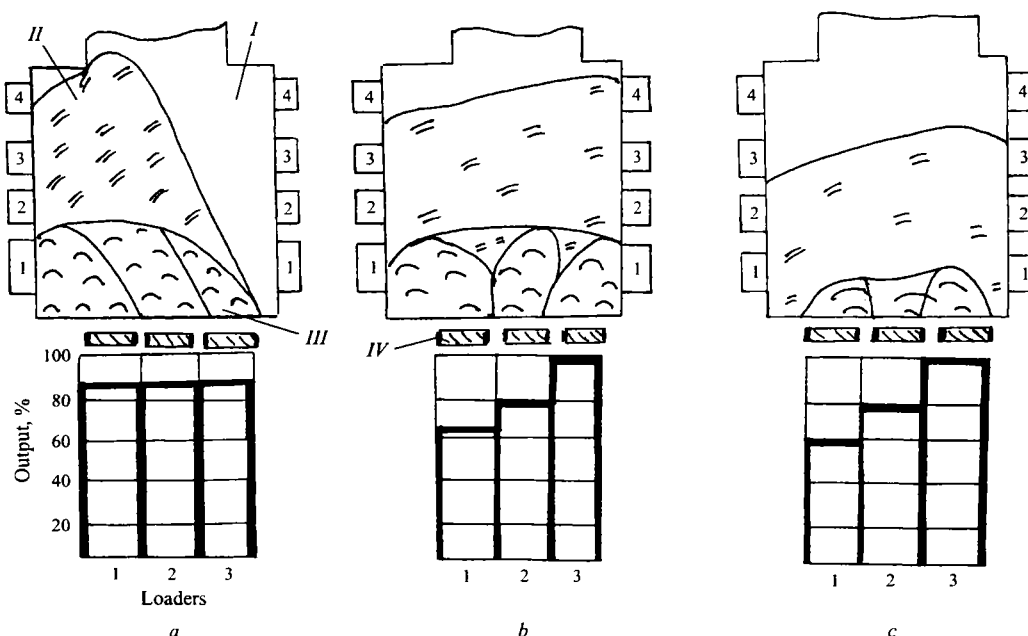


Fig. 1. Charts of the position of glass-melting zonal boundaries and relative output of the loaders: *a*) before the beginning of the investigation; *b*) after modification of the batch ROP and introduction of differentiated batch loading; *c*) after modification of flame switch and redistribution of thermal loads among the burners (*I* – 4); *I*) mirror surface; *II*) foam; *III*) batch heaps; *IV*) batch and cullet loaders.

in the maximum melting temperature from 1510°C (process 2a) to 1530°C (process 2b).

Some technical problems in the operation of the regenerator packing (the studies were performed before the replacement of the packing) resulted in the fact that the batch melting proceeded asymmetrically with respect to the tank furnace longitudinal axis. The batch and foam zone was located on the left side of the furnace and the froth reached the barrier device. The high-temperature fluid glass (the mirror surface) was on the opposite (right) side of the furnace. Measurements of the glass melt temperature in the working zone at a depth of 100 mm revealed a lower temperature on the left side of the furnace (Table 1, process 2b). The asymmetric distribution of froth and the mirror surface resulted in the output of fluid glass exhibiting a high temperature and substantial chemical inhomogeneity, which persistently generated a substantial amount of longitudinal cracks on the glass band. Moreover, this was the reason for the intense wear of the furnace brickwork at the site of contact with the batch.

The above facts pointed to the disturbance of the normal glass-melting process: in spite of two transverse convective flows (according to the standard scheme [5]), there was one convective flow which deflected the batch and the foam to the left side of the furnace (Fig. 1a).

The main reserve for the intensification of glass melting consisted in the elimination of the asymmetrical distribution of the melting zones. However, the heat insulation of the main roof carried out at the beginning of the investigation and the attempt to increase the maximum temperature in the tank furnace by 20°C by increasing the thermal load on the

second pair of gas burners did not produce a positive result. Consequently, it was decided to increase the melt diathermancy by means of a gradual increase in its oxidizing potential and to shift the equilibrium of the valence forms of iron toward Fe(III), whose tinting effect on the glass melt is less perceptible. For this purpose, part of the reducer (carbon) was gradually removed from the batch. In the end, the batch ROP increased from 16.25 to 20.19 (Table 1), as a consequence of which the foam zone surface on the left side of the furnace decreased by 15 – 20%.

At the same time, in order to balance the positions of the melting zone boundaries with respect to the longitudinal axis of the furnace, differentiated batch loading was implemented, which consisted in a decreased feed of batch and cullet to the left (cold) part of the furnace and the proportional increase in the feed of the other loaders (Fig. 1b).

Certain measures were taken as well to equalize the temperatures of the packing of the regenerators. First, the operating period of the right (the colder) regenerator was delayed by 40 min, instead of the earlier accepted 30 min lag. After the right regenerator packing was heated, the flame was switched every 20 min. Next, the thermal loads on the burners were redistributed: the feed of gas to the burners in the front part of the furnace was increased (Fig. 1c).

Owing to the implementation of a set of chemical and physical methods for the intensification of glass melting, intense melting of batch began on both sides of the furnace in the region of the first pair of burners. Several hours later, the high-temperature backflow of the glass mass deflected to the left (cold) side of the furnace and the boundary of the batch

and foam shifted towards the doghouse. The foam zone decreased substantially. The maximum glass melting temperature in the gas medium decreases by 15 – 20°C (see Table 1, process 2c). The use of almost the same types of local raw materials resulted in reduction of the Fe(II) content from 0.0034% (process 2b) to 0.0028% (process 2c), whereas the glass melt ROP increased: the Fe(II) content decreased from 36.9% (process 2b) to 31.4% (process 2c). The controlled increase of the glass melt ROP resulted in the leveling of the glass melt temperatures and an increase in the tank furnace efficiency (without additional increase in the fuel consumption).

Thus, the physical and chemical methods for glass melting intensification represent significant internal reserves for improving glass quality and the operating and economic parameters of the glass-melting system.

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